Driving the FUTURE OF PERSONAL TRANSPORTATION

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“Focus on the Future” Automotive Research Conferences
“Powertrain Strategies for the 21st Century: Looking Beyond 2016”

July 14, 2010
New U.S. Fuel Economy Standard

GM is fully committed to the new EPA Green House Gas rules to improve vehicle fuel economy and lower emissions

Final Rules (2012-2016 MODEL YEARS):
- Harmonizes National Greenhouse Gas Program (EPA responsibility) and Corporate Average Fuel Economy (CAFE) Standards (NHTSA responsibility)
- Requires a US fleet average fuel economy of 35.5 mpg (250 g CO₂ per mile) by 2016 model year
- Benefits consumers by getting cleaner, more efficient vehicles on the road quicker and more affordably
- Benefits the environment through reduced CO2 emissions
- Benefits the auto industry by having more consistency and certainty to guide our product and technology plans
Global Energy Consumption to 2030 - The projections in 2006

- **2006**: 85 MBD
  - 1,000 barrels/second!
- **2030**: 120 MBD projected
- 50% used for transportation
- Transportation is 96% dependent on petroleum

Source: DOE-EIA 2006
Global Energy Consumption to 2030 - The projections in 2006

Source: DOE-EIA 2006

2008 Update (IEA)
- 2008: 86MBD
- 2030: 106MBD projected
## World Oil Demand at Different Oil Intensities

<table>
<thead>
<tr>
<th>Oil Intensity Barrels/Person/Year</th>
<th>Global Oil Demand at this Oil Intensity Million Barrels Per Day (MBD)</th>
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<tr>
<td></td>
<td>In 2010</td>
<td>In 2020</td>
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<td>25.2 (US 2007)</td>
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<td>524</td>
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<td>14.3 (Japan 2007)</td>
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<td>4.76 (World 2007)</td>
<td>86</td>
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Source: Historical data from IEA and US Bureau of the Census data
Significant new Capacity is Required to make up for Declines in Existing Capacity!

Source: IEA World Energy outlook, 2008
Impact of Urbanization and Traffic Congestion

- Over the next decades, all of the world’s population growth will be in urban areas, with Asia and Africa accounting for 90% of the growth.
- By 2030, urban areas are projected to account for 60% of the population and greater than 80% of the wealth.
- Implications for transportation systems:
  - Personal vs. mass transportation
  - Low-/zero-emission capability
  - Growth of “Urban Vehicles”
By 2020:
- 27 Mega Cities (>10M)
- 9 Hyper Cities (>20M)
London’s population density profile

Source: Mats Andersson, World Bank (2005)
New York’s population density profile

Source: Mats Andersson, World Bank (2005)
Shanghai’s population density profile

Source: Mats Andersson, World Bank (2005)
Population Density and Driving Speed

R² = 0.7295

GM Strategy: Displace Petroleum Through Energy Diversity & Efficiency
Advanced Propulsion Technology Strategy

- Improve Vehicle Fuel Economy and Emissions
- Displace Petroleum
- Hydrogen Fuel Cell-Electric
- Battery-Electric Vehicles (including E-REV)
- Hybrid-Electric Vehicles (including Plug-In HEV)
- IC Engine and Transmission Improvements

Energy Diversity
- Petroleum (Conventional and Alternative Sources)
- Alternative Fuels (Ethanol, Biodiesel, CNG, LPG)
- Electricity (Conv. & Alternative Sources)
- Hydrogen
Achieve the maximum fuel economy and the minimum emissions potential for a diverse range of application through synergistic integration of building block technologies.

Charge Boosting, Charge Dilution, Active Sensing, and Electrification will be the focus in the future.
Gasoline engines will use building block technologies.

Numbers are estimates and not additive.
Diesel Engines – Achieving the Lowest Emissions

Base Engine Technologies
- High Pressure Injection
- Lower Compression Ratios
- Higher Peak Cylinder Pressure

Advanced Boosting with Small Displacement

Cylinder Pressure Sensing

PCCI Combustion

Diesel Particulate Filter

NOx Aftertreatment

High Pressure Injection

Lower Compression Ratios

Higher Peak Cylinder Pressure

HP Turbo

LP Turbo

ECU

EGR

Turbo

Cylinder Pressure Sensor

Porous Cell Wall

Oxidation Catalyst

Urea Injection

SCR Urea NOx Catalyst

Particulate Filter

PCCI Combustion

Conventional Combustion

PCCI Combustion

NOx Zone

Soot Zone

Equivalence Ratio (f)

Temperature (K)

0

500

1000

1500

2000

2500

3000

500

1000

1500

2000

2500

3000

0

1

2

3

4

5

6

Urea Injection

SCR Urea NOx Catalyst

Particulate Filter

Oxidation Catalyst
Building block technologies for automatic transmissions

- Aggressive Shift/TCC
- Thermal Management
- Reduced Spin Loss
- Low Viscosity ATF
- Downsized Pump
- Controlled Lube
- Neutral Idle
- Selectable OWC
- Variable K-factor TC

- Architecture Change
- Trans Enablers for Start/Stop
- Lower Loses and Improved Efficiency
- Optimized Operating Points

Baseline

Fuel Economy Improvement

Time

Numbers are estimates and not additive
### GM Hybrid & Electric Vehicles

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GM Hybrid System

Stop/start
Boost assist
Opportunity charging
Deceleration fuel cutoff
Regenerative braking
Automatic transmission
10%-25% FE gain
Most Affordable
2-Mode RWD Hybrid System

GMC Yukon 2-Mode Hybrid

- Two 60 kW Electric Motors
- 300V, 1.8 kW-Hr NiMH Battery
- Power Electronics System
- 6.0L V8 Engine
- 50% city fuel economy improvement
- City fuel economy equal to 4-cyl Camry
- Tow up to 6,200 pounds

Chevrolet Tahoe 2-Mode Hybrid

- 332 hp / 367 lb-ft
- 2-Mode Transmission
- Two 60 kW Electric Motors
2-Mode FWD Hybrid System

2009 Saturn VUE Green Line
Up to 50% fuel economy improvement
Exceptional fuel economy and performance
Provide the basis for PHEV capability

260 Hp, 3.6L SIDI V6 Engine
300V, 2.2 kW-Hr NiMH Battery
2-Mode Transmission
Two 55 kW Electric Motors
Power Electronics System
**Biofuels Technology Roadmap**

**1st Generation**

**Feedstock:** Sugars, Starch ➔ Cellulose

- Sugarcane
- Corn
- Sugarbeet, ...
- Cassava
- Sweet Sorghum

**Fuels and Conversion Products**

- Ethanol
- Biodiesel
- FAME

**2nd Generation**

- Grasses
- Wood biomass
- Cellulosic

**Conversion Products**

- Ethanol
- Alcohol
- FAME
- Biodiesel
- Hydro-treated Biodiesel

**3rd Generation**

- Designer energy crops
- Designer bacteria convert CO2 directly to final fuel products

**Conversion Products**

- Biocrude
- Pyrolysis
- Green hydrocarbons

**Conversion Products**

- Bio-oil to Green Fuels
- Alcohols

**Conversion Products**

- Algae

**Feedstock:** Oil-seed / Waste Lipids ➔ Algae

- Soybeans
- Jatropha
- Palm oil
- Camellina
- Rapeseed
- Tallow
- Waste veg. oil

**Conversion Products**

- Algae
GM is committed to the rapid commercialization of “The Next Generation of Ethanol”

GM has announced strategic alliances with two leading cellulosic ethanol start-ups, Coskata and Mascoma, that cover the biothermal and biochemical spectrum in advanced biofuel technology

Partnership is about accelerating putting next generation of cellulosic ethanol on the market
Coskata’s Leading Feedstock Flexible Ethanol Process

3-Step Process is efficient, affordable, feedstock flexible:

1. Incoming material is converted into a synthesis gas by gasification
2. The synthesis gas is fermented to ethanol using bacteria
3. Ethanol is separated and recovered using membrane technology
Coskata's Technology: Flexible and Affordable

- Able to use multiple non-food based products around the globe
  - For example:
  - Wood Waste
  - Grasses/Energy Crops
  - Municipal and Industrial Wastes

- Will produce ethanol that will be competitive with gasoline, unsubsidized in the long term
  - Yields over 100 gal/dry ton biomass of fuel grade ethanol
  - Returns up to 7.7 times as much fossil energy as what is used to produce the fuel
  - Uses less than one gallon of fresh water per gallon of ethanol
  - Reduces green house gas emissions by up to 96%
Can Large-Scale Biofuels Provide a Real and Sustainable Solution to Reducing Petroleum Dependence?

1. What must happen to grow ethanol production to 90B gal by 2030?
2. What is required for cellulosic ethanol to be cost competitive with gasoline?
3. What are the associated greenhouse gas, energy, and water footprints?
4. What risks could impact cellulosic ethanol’s production and competitiveness goals and how can we mitigate these?
Biomass for 90 billion gallons of ethanol can be produced largely without reducing current active cropland.

- 44 M acres cropland as pasture and idle cropland
- 40 M acres non-grazed forest land
- No land use change for residues
- equals 2006 corn ethanol acreage

SRWC: Short Rotation Woody Crop
GM EN-V CONCEPTS FOR 2010 WORLD EXPO IN SHANGHAI
(“BETTER CITY, BETTER LIFE”)

- Fashionista
- Cute & Friendly
- Techno-geek
PROJECT DRIVEWAY

5,000
ORDINARY DRIVERS

1,300,000
MILES LOGGED
Diverse Customer Needs
Hydrogen Fuel Cell Chevrolet Equinox – at Work

Customer Expectations: No Compromises
PRODUCTION-INTENT FUEL CELL SYSTEM (FCS)

- Half the size, 220 pounds lighter, and uses ~third of the platinum in Equinox FCS

- Compared to internal combustion engine:
  - Twice as efficient
  - Promises equivalent durability, range (300 miles), and performance
  - 60% fewer part numbers
  - 90% fewer moving parts
  - Similar refueling time (~3 minutes)
$100-200 million H₂ infrastructure investment opens 15 million driver market

Examples - Hydrogen Infrastructure in Deployment

Germany beginning infrastructure installations (1,000 H₂ stations), supporting Daimler’s 2013 & 2015 production fuel cell programs

Japan announced infrastructure & vehicle deployment plans (1,000 H₂ stations & 2 Million vehicles by 2025)

- 30-40 stations ≈ 3.6 miles apart
  - Los Angeles Metro Area
- 10 stations ≈ 25 miles apart on destination corridors
  - San Diego
  - Palm Springs
  - Las Vegas
  - Santa Barbara

Regional H₂ infrastructures can be achieved with 40-50 stations in metro areas & along major destination corridors
Advanced Propulsion Technology Strategy

- Improve Vehicle
  Fuel Economy and Emissions

- Displace Petroleum

- IC Engine and Transmission Improvements

- Hybrid-Electric Vehicles (including Plug-In HEV)

- Battery-Electric Vehicles (including E-REV)

- Hydrogen Fuel Cell-Electric

Energy Diversity

- Petroleum (Conventional and Alternative Sources)

- Alternative Fuels (Ethanol, Biodiesel, CNG, LPG)

- Electricity (Conv. & Alternative Sources)

- Hydrogen
Thank You For Your Attention